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LARGE TIME SCALE VARIATION IN HYDROGEN EMISSION FROM JUPITER AND SATURN

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ABSTRACT

IUE and Voyager spacecraft observations of Jupiter and Saturn have been combined to obtain a consistent measurement of temporal variation of the equatorial subsolar hydrogen emission. The outer planets appear to have rather independent behavior over time scales of the order of 10 years, particularly in emission from the H Lyα line The time interval from 1978 to the present shows variation of mean equatorial H Lyα brightness of ≈ 2 at Jupiter and ≈ 5 at Saturn The relative magnitudes of the variations is sufficiently different to suggest that response to input from the sun is at least nonlinear. The brightness of H_2 band emission appears to be relatively more stable than H Lyα. There is evidence in IUE observations of a moderate increase in H_2 band brightness with increasing time at Jupiter, in opposition to the variation in H Lyα

Keywords/Solar system/atmospheres

1. INTRODUCTION

Emission from atomic and molecular hydrogen is an understandably dominant feature in the EUV spectra of the outer planets, particularly on the sunlit hemispheres. A current question of high interest involves the fundamental issue of exactly what process produces electronically excited states in the gas to generate the observed emission. The auroral emissions are certainly produced by particle precipitation, but the prominent emissions from the sunlit equatorial regions are spatially diffuse and the interpretation of how the gas is excited is less obvious. The strong emission of the H_2 Rydberg band systems has been interpreted as primarily collisionally induced by electrons (see Ref. 1). This conclusion was based on the fact that an electron excited model accurately matched the spectrum and on the estimation that fluorescence of solar radiation should be very weak. However, more recently (Ref. 2) it has been suggested that fluorescence may play a more dominant role in the excitation process through application of a model using a brighter solar EUV source and converting most of the flux into fluorescence. The difference between these conclusions has significant implications for the energetics of the atmosphere. If the source is dominantly electron excitation, the relatively high temperatures at the top of the thermospheres of Jupiter, Saturn and Uranus could be explained by heating produced as an intrinsic part of the process (Ref. 3). Some other explanation of the thermal structures would have to be found if the fluorescence process dominated.

We describe below an analysis of observations obtained at the Voyager spacecraft encounters in combination with the long time line of measurements provided by the IUE satellite. We find that although the interpretation of the H Lyα emission in terms of atmospheric excitation processes is more difficult, the observed temporal variations are very distinctive, and planet to planet variations are also evident. The results appear not to be compatible with an atmosphere responding only to the deposition of solar radiation.

2. ANALYSIS OF OBSERVATIONAL DATA

Several factors affect the data reduction process particularly in the extraction of the planetary emission rate of H Lyα (1216Å) from the observed spectrum. The measured signal at 1216Å includes H Lyα emission in varying amounts from the local geocorona, emission from the local interstellar medium (LISM) along the line of sight to the planet, and in the case of Saturn a portion of the SWP large aperture includes emission along the line of sight beyond the location of the planet. The effect of extinction of the H Lyα signal from the planet is also significant for Saturn in particular. All of these effects were accounted for in the analysis through the use of a geocoronal model developed in this program, and a model of the LISM (Ref. 4). Most of the IUE SWP spectra of Saturn were reduced in a line by line analysis of the image in order to obtain uncontaminated measurements of the equatorial region.

2.1 Jupiter

The H Lyα emission from Jupiter's equatorial region shows two separable temporal characteristics. The bulge phenomenon associated with a broad magnetic longitude region (~125° FWHM) with enhanced emission centered on 110° λ_{III}. The results obtained in the current observational program and earlier analyses show that the phenomenon is always present and has persisted with approximately the same amplitude since 1979 (Refs. 1, 5). Figure 1 shows data from August 1984, April 1985, and November 1986 as a function of central meridian longitude (CML) obtained from the current observational program. The amplitude and general shape and location of the CML modulation is essentially unchanged from results derived from earlier observations (Refs. 6, 7, 1, 5,). The data in Figure 1 shows an emission peak near 105° CML and a minimum near 290° CML. The consistency in location shows that the phenomenon is defined in an absolute sense by λ_{III} magnetic longitude. The magnitude of the modulation according to the IUE data shown here and the results reported by Ref. 5. suggests some variability The mean modulation shown in Figure 1 is ~1.45 in peak to trough ratio. Values reported by Ref. 5. vary from 1.7 to 1 05 with no clear long

TABLE I

Jupiter sub-solar brightness with no correction for ISM/IPM extinction

Observation	Date	I(H_2Ly+WR) (kR)	I(H Lyα) (kR)	I(H Lyα) / I(H_2Ly+WR)	I(1600A) (R/A	λ_{III} CML	Remarks
Rocket [a]	1972/144	2 4	1	0 4	50	100	Disk Average
		3 1	1 5	0 5	74	100	Calculated Sub-solar Point
Rocket [b]	1978/335		13			106	Disk Average
	1978/335		19			106	Sub-Solar Point
IUE [c]	1979/158				74		Sub-Solar Point
V2 [d]	1979/187	3 0	16	5 3	76	240-330	Sub-Solar Point
V2 [d]	1979/187	3 0	22	7 2	65	60-150	Sub-Solar Point
IUE [e]	1979/120 -150		15			100	Sub-Solar Point
IUE [e]	1980/120 -180		12			100	Sub-Solar Point
IUE [f]	1985/99	4 4±1 6	8 0	1 8	76±6	100	Sub-Solar Point
IUE [f]	1985/99	4 4±1 6	5 8	1 3	76±6	280	Sub-Solar Point
IUE [f]	1986/304		8 2	1 6		100	Sub-Solar Point
IUE [f]	1986/304	5 2±1 5	6 0	1 1	85±6	280	Sub-Solar Point
IUE [f]	1986/305	5 4±1 7	7 5	1 4	86±5	280	Sub-Solar Point

a) Judge and Shemansky (1985) analysis of Giles et al (1976) rocket experiment, E-W H bands distribution shows no limb darkening (Shemansky, 1985)
b) Clarke et al (1980) rocket experiment
c) Present work, estimate from SWP 5448
d) Shemansky (1985) analysis of V2 data
note: I(1600A) - 0 43, Table 3 should read "Atmospheric Reflection 1660A, Solar" I(1660A)
e) Clarke et al. (1981a) corrected upward by a factor of 1 16 on 1983 correction to IUE aperture size
f) Present work.

Table 3

Rough estimate of extinction by the ISM/IPM for observations of H Ly α

Obs.	Date	I(H Ly α)[a] (kR)	τ[b]	Ic(H Ly$_J$)[c] (kR)	Ic(H Ly α) / I(H Ly+WR)	λ_{III} CML
Jupiter						
Rocket	1972/144	1.5	0.03	1.6	0.51	100
Rocket	1978/355	19.	0.11	21.2		100
V2	1979/187	22.	0.00	22.0	7.2	60-150
IUE	1980/120 /150	15.	0.07	16.0		100
IUE	1980/120 /150	12.	0.21	14.8		100
IUE	1985/99	8.	0.15	9 3	2.2	100

Obs.	Date	I(H Ly α)[a] (kR)	τ[b]	Ic(H Ly$_J$)[c] (kR)	Ic(H Ly α) / I(H Ly+WR)
Saturn					
IUE[d]	1980/126,130	1.58	1.16	5.06	
IUE[d]	1980/322,323	1.60	0.95	4 13	
V1	1980/316	4.90	0.00	4.90	5.3
V2	1981/236	3.00	0.00	3.00	2.8
IUE	1986/252,254	0.84	0.17	0 99	
IUE	1987/114	1.21	0.10	1.33	
IUE	1987/204,205	0.87	0.13	0.99	

a) Brightness before correction for extinction
b) Calculated optical thickness (see text)
c) Brightness after correction for extinction
d) Ref. 10 corrected upward by factor of 1.16 on basis of 1983 correction to IUE aperture size. Saturn is known to have no limb darkening effect in H Ly α and therefore no limb darkening corrections are applied to the measured data.

TABLE 2

1986 DOY 252 and 254 SATURN IUE OBSERVATIONS OF H LYα

SWP	Exposure Duration (Min)	Scattering Background ((FN/S)	ILy-α Observed (kR)	ILy-α Geocorona (kR)	ILy-α[c] ISM (kR)	ILy-α[b] Saturn Emission (kR)
29170[a]	30	---	0.917	0.295	0.622	----
29172	80	2.83	2.862	1.651	0.508	0.976
29173	30	2.65	3.137	2.019	0.508	0.849
29174[a]	15	---	2.276	1.593	0.622	--
29175	15	2.25	2.295	1.220	0.508	0.788
29176	25	2.83	1.979	0.920	0.508	0.765
29177	25	2.50	1.747	0.686	0.508	0.768
29189[a]	30	---	2.166	1.604	0.622	---
29190	30	2.39	2.220	1.124	0.508	0.817
29191	30	2.27	1.903	0.803	0.508	0.822
29192	15	2.37	1.819	0.625	0.508	0.953
WEIGHTED MEAN						0.88±0.2

a - Sky Background Observation (60" N of Saturn)
b - Implied Saturn Emission = $(I_{OBS} - I_{ISM} - I_{GEOCORONA})/.72$
c - $I(Ly\text{-}\alpha)_{ISM} = [I(Ly\alpha)_{ISM_\infty}]*.28 + [I(Ly\alpha)_{ISMSAT}]*0.72$
$I(Ly\alpha)_{ISM_\infty} = 0.622$ kR
$I(Ly\alpha)_{ISMSAT} = 0.463$ kR

term trend.

The long term variation of the Jupiter H Lyα emission is shown in Figure 2, which combines results from Voyager and IUE for the outer planets. The variation of the anti-bulge emission rate over the time period 1979-1987 is approximately a factor of 2, in agreement with the results recently reported by Ref. 5. The IUE measurements at Jupiter are corrected for extinction by the LISM; the extinction effect for Jupiter H Lyα is expected to be small, but may account for the slightly larger Voyager values. Extinction of the H Lyα line has also been corrected in the analysis of the Saturn and Uranus data as, described below.

The IUE SWP system is the only experimental system currently capable of providing measurements of the H_2 Lyman and Werner Rydberg bands in the equatorial region. The total brightness of the H_2 bands (Lyman + Werner , I(H_2 Ly+Wr)) is estimated by comparison with model calculations (see Ref. 1). Brightness values for various observations, including rocket and Voyager data, are compiled in Table 1. The values for I(H_2 Ly+Wr) obtained from the IUE data tend to be larger than the earlier Voyager and rocket data (Table 1, see Ref 7). However, uncertainty in the measured quantities overlap the earlier results The results derived here from the more recent IUE data, particularly near the end of 1986 (Table 1), indicate that the H_2 Lyman and Werner bands were as bright or brighter at solar minimum as they were near solar maximum in 1979.

Table 1 includes the measured differential brightness at 1600Å, which represents the reflection of solar continuum radiation near the homopause This region of the solar spectrum is essentially constant in absolute flux compared to the temporal variability of the shorter wavelength radiation. The various measurements of this quantity obtained from 1972-1987 (Table 1) show that within measurement error the equatorial subsolar flux at 1600Å is constant (see Ref. 7). The comparison of the results from the different experiments at 1600Å provides confidence in the absolute calibrations.

2.2 Saturn

Analysis of the equatorial emission spectra of Saturn is restricted to the determination of H Lyα brightness and the solar reflection continuum at 1600Å. The factors affecting the determination of the H Lyα brightness as discussed above, are more critical at Saturn than Jupiter because of the greater distance to the planet combined with weaker source rates. Table 2 shows the sequence of observations with the measured H Lyα intensity in column 4 Interspersed with the Saturn observations are background data obtained 60" north of the planet. These background data may contain contributions from the Saturn corona (Ref. 3) but we have not attempted to remove this component from the analysis due to lack of a reference point This problem will be corrected in subsequent observations. Background is composed of geocoronal and LISM components as estimated in column 5 and 6 of Table 2. The data also contain a foreground component from the Saturn corona, but none of the reported observations including the Voyager results (Refs. 8, 2, 3,) are corrected for this contribution. Although the observed emission brightness varied from ~ 3.1 kR to ~ 1.8 kR during the sequence, most of the variation appears to be caused by the geocoronal component, and the derived Saturn emission brightness is basically constant during the sequence with an estimated mean value of I H Lyα = 0 88±.2kR (Table 2). The geometry for the 1986 DOY 252,254, observations is ideal in the sense that the planet is essentially directly upstream from the earth relative to the bulk flow of the LISM, so that extinction of the planetary signal is at a minimum. However, the observing geometry at the time of the Ref. 9 observations indicates a substantially larger extinction factor. Estimates of the extinction coefficient are given in Table 3. The coefficient has been normalized by analyzing the IUE data obtained near the time of Voyager encounters in 1980 and 1981. As shown in Figure 2, the H Lyα line according to the combined Voyager and IUE data, declined significantly by a factor of about 5, between November 1980 and August 1986. The Voyager data above indicates a reduction by a factor of 1.7 in the ~ 1 year interval between encounters, a period in which the solar H Lyα line showed no significant long term variation.

3. DISCUSSION AND CONCLUSIONS

The rather independent behavior of the three outer planets in relation to each other and to the major solar cycle indicated in the results compiled here for H Lyα subsolar emission rates suggests that the responses of the atmospheres to solar radiative energy deposition is substantially decoupled or at least very nonlinear. Jupiter shows a long term trend from solar maximum to solar minimum of a factor of about 2 comparable to the variation of the solar H Lyα flux. In the same period, the Saturn emission rate declined by a factor of 5. Uranus, according to the Ref. 9 results shows no particular trend from 1982 although there is variability. The observations of Jupiter in the present IUE program are in agreement with the recent results reported by Ref. 5, in respect to both the H Lyα bulge phenomenon and temporal trend on the time scale of the 11 year solar cycle. Although this variation corresponds well to the trend in solar H Lyα flux over the same period, two facts tend to argue against a direct correlation First, results obtained by Ref. 7 indicate that H Lyα brightness in 1974 was an order of magnitude below the value in 1979 showing a poor correspondence with the magnitude of the solar line variation. Second, the H Lyα bulge phenomenon persists with the same magnitude in mean modulation during the years 1979-1987. The H Lyα bulge is obviously unrelated to solar flux variability. The process appears to be impossible to explain in terms of response of the atmosphere to the deposition of solar radiation.

The H Lyα emission of Saturn shows a variation of a factor of 1.7 between November 1980 and August 1981, while emission from Jupiter as well as solar flux remained basically constant over the same period. Overall, the variation of Saturn H Lyα emission is a factor of 5 from November 1980 to August 1986 (Figure 2)

The difficulty in determining and differentiating the processes controlling the emission of H Lyα mainly stems from the fact that atomic hydrogen is a minor atmospheric constituent. The abundance of HI in the atmosphere is therefore subject to a number of source and sink processes, and given the extent of available information it is difficult to determine whether variation in observed H Lyα emission rate is caused by variation in the excitation rate, in the abundance of the gas or in a combination of the two effects The problem is complicated by the fact that some reactions producing H Lyα emission are also directly related to the production of atomic hydrogen. One of the puzzling aspects of the observed atmospheric behavior on both Jupiter and Saturn is the fact that emission in the H_2 Rydberg bands, which serve as at least one indicator of H_2 dissociation rate, do not correlate well with the observed variation of H Lyα. the H Lyα transition is excited by both electrons and resonance scattering. Dissociative excitation of H Lyα is only a small component of the observed total.

A major factor contributing to the uncertainty in understanding the behavior of H Lyα lies with the processes controlling the sink for atomic hydrogen in the atmosphere. This problem has been discussed previously by Ref. 7. The removal of atomic hydrogen from the atmosphere, apart from the process of escape (Ref. 3), can only take place by transport to the homopause with subsequent recombination. It is not clear that the factors controlling rates for this process can show substantial variability.

On the whole the evidence seems to indicate that a substantial fraction of the observed emission must be electron excited.

The persistent H Lyα bulge phenomenon on Jupiter and the tendency for independent behavior between the planets are very difficult to explain without the introduction of particle energy deposition.

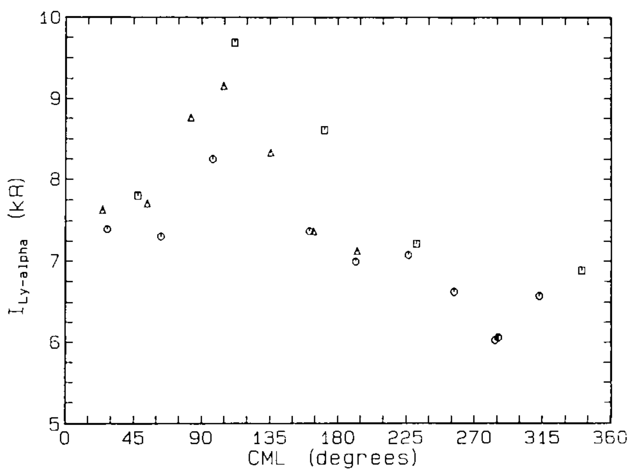

Figure 1. Jupiter subsolar H Lyα brightness, calculated from IUE measurements in 1984–1986, as a function of CML. Geocoronal and LISM components have been removed using model calculations referenced to interspersed IUE background measuremnts. □□ symbols – August 1984; ○○ symbols - April 1985; △△ symbols – November 1986.

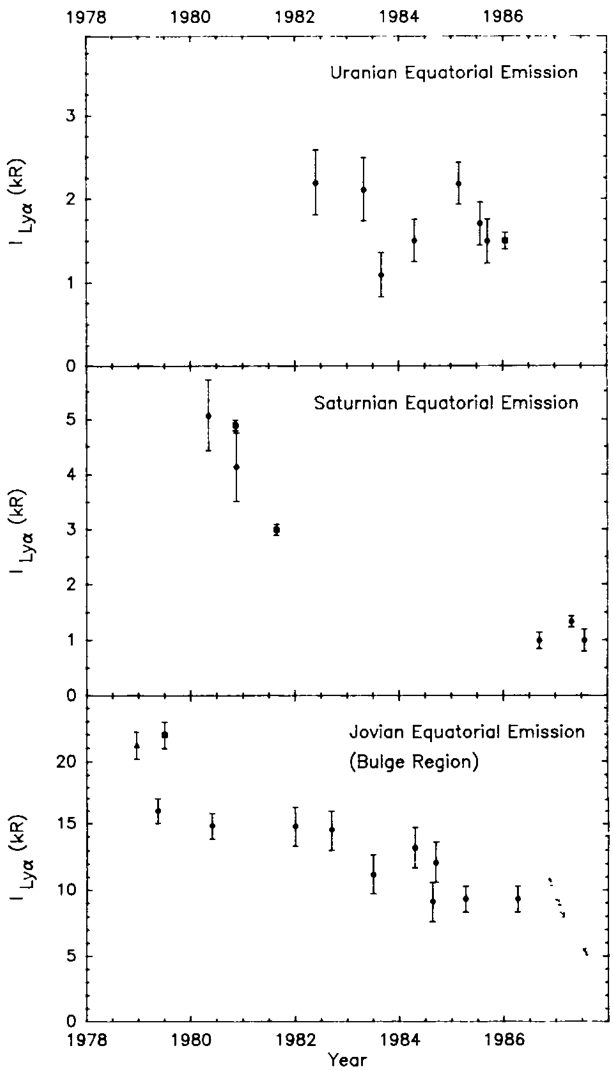

Figure 2. Long term variation of H Lyα subsolar emission rate for Jupiter, Saturn and Uranus. The data for Jupiter and Saturn is obtained from Voyager, rocket and IUE measurements The results for Uranus are averages from IUE measurements by Ref 9. The IUE data has been corrected for estimated extinction by the LISM. The rocket data point (△) at Jupiter was obtained 1978 DOY 335 by Ref. 10. The Voyager data are indicated by square symbols, and IUE by circular symbols.

4. REFERENCES

1. Shemansky, D E 1985, An explanation for the H Ly α longitudinal asymmetry in the equatorial spectrum of Jupiter; An outcrop of paradoxical energy deposition in the exosphere, *J Geophys Res* vol 90, 2673
2. Yelle, R V, et al. 1987, The dependence of electroglow on the solar flux, *J Geophys Res* vol 92, 15110.
3. Shemansky, D E and D T Hall 1987, Atomic hydrogen in the magnetosphere of Saturn and Uranus, *Bull AAS* vol 19, 850.
4. Ajello, J M et al 1987, Solar cycle study of interplanetary lyman alpha variations; Pioneer Venus orbiter sky backgrtound results, *Ap J* vol 317, 964.
5. Skinner, T E et al 1988, Temporal variation of the Jovian HI lyman-alpha emission (1979-1986), *J Geophys Res* vol 93, 29.
6. Sandel, B R, A L Broadfoot, and D F Strobel 1980, Discovery of a longitudinal asymmetry in the lyman-alpha brightness of Jupiter, *Geophys Res Lett* vol 7, 5.
7. Shemansky, D E and D L Judge 1988, Evidence for change in particle excitation of Jupiter's atmosphere 1968–1979, *J Geophys Res* vol 93, 21.
8. Shemansky, D E, and J M Ajello 1983, The Saturn spectrum in the EUV electron excited hydrogen, *J Geophys Res* vol 88, 459.
9. Clarke, J T et al. 1986, Continued observations of the H Ly α emission from Uranus, *J Geophys Res* vol 91, 8771-81.
10. Clarke, J T et al. 1981, IUE detection of bursts of H Lyα emission from Saturn, *Nature* vol 290, 226.
11. Clarke, J T et al. 1980, Spatial imaging of hydrogen Lyman α emission from Jupiter. *Ap J* vol 240, 696

5. ACKNOWLEDGMENT

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